DR19.11 LOC-GFO-19-301-4 Optimizing Heat Pump Load Flexibility

Overview

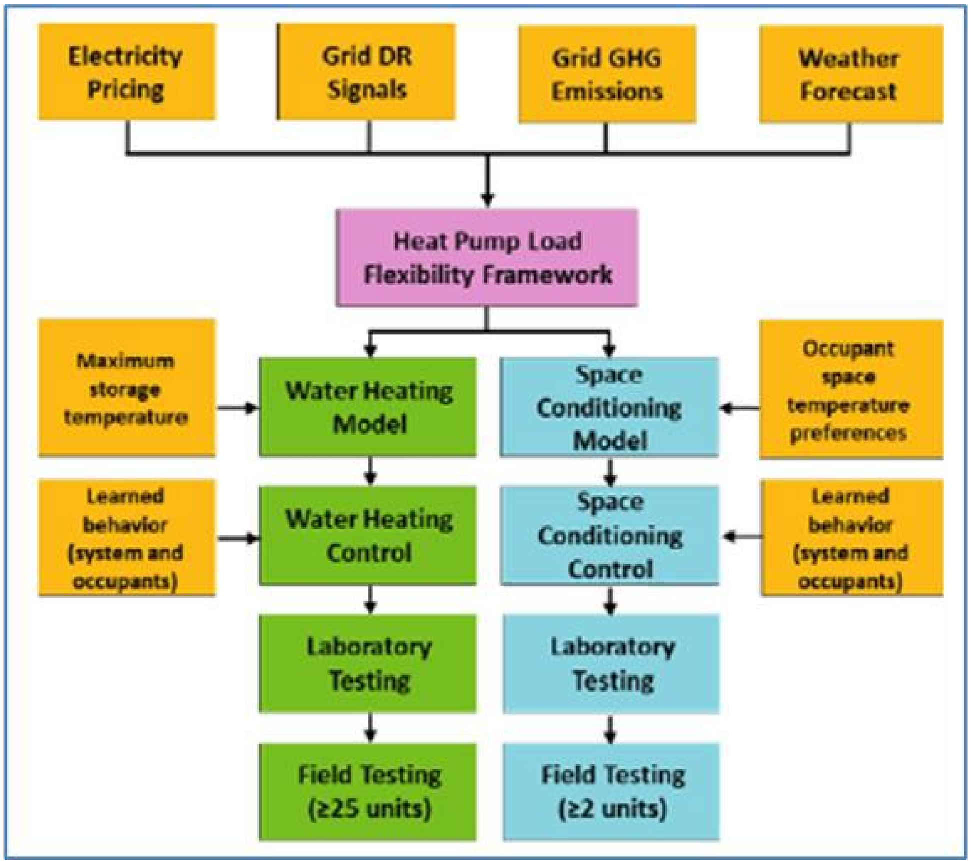
This CEC EPIC project which SCE is co-funding will develop, test, and demonstrate an open-source framework for heat pump load flexibility controls that will be employed for both Advanced Water Heating Controls (AWHC) and Advanced Space Conditioning Controls (ASCC), with the goal of providing a common platform that can be leveraged to manage residential electricity use across multiple types of equipment and devices. The control system optimizes heat pump operation based on: 1) Building owner/occupant preferences, comfort, and use patterns; 2) Electricity pricing, including time-of-use schedules and/or hourly or sub-hourly price signals; 3) Electricity grid needs, which may be reflected in ways other than price signals (e.g. demand response (DR) signals; 4) Electricity grid real-time greenhouse gas (GHG) emission rates; and 5) Weather data (current and forecasted).

Tackling both space conditioning and water heating controls from a common framework is useful and efficient, as most of the data needed for a heat pump load controller (e.g., electricity pricing, grid DR signals, grid emissions, weather) are not specific to the heat pump end-use type (Figure 1). By applying one framework to both water heating and space conditioning equipment, the project will demonstrate the scalability and futureproofing of heat pump load control systems that are compatible with future investments in synergistic technologies. In this way, designing both water heating and space conditioning controls within a single framework will facilitate future integration of additional equipment and simplify the process of obtaining, configuring, and monitoring advanced controls.

The AWHC control modulates hot water tank storage temperature to store thermal energy and achieve the optimal system performance, where the optimization is based on a utility price schedule or signal, a GHG emission signal, and a utility DR signal.

Heat pumps for space conditioning and water heating are currently controlled using rule-based logic to maintain a programmed water temperature or an indoor air temperature setpoint. While this approach is proven and robust for maintaining a user-defined setpoint, this type of control does not provide any flexibility for the timing of heat pump operation. For example, whenever the water or air setpoint is not satisfied, the rule-based control will run the heat pump until the setpoint is satisfied, regardless of the cost of electricity or the electrical grid GHG emissions rate.

The ASCC will modulate the housing unit’s temperature setpoint to store thermal energy and achieve the optimal system performance, where the optimization is based on utility price schedules or signals, GHG emission signal, and utility DR signals. Load flexibility controls offer a way for customers to shift consumption to times of day with lower rates without compromising their comfort. For load flexibility controls to be widely adopted, building occupant preferences must be satisfied.

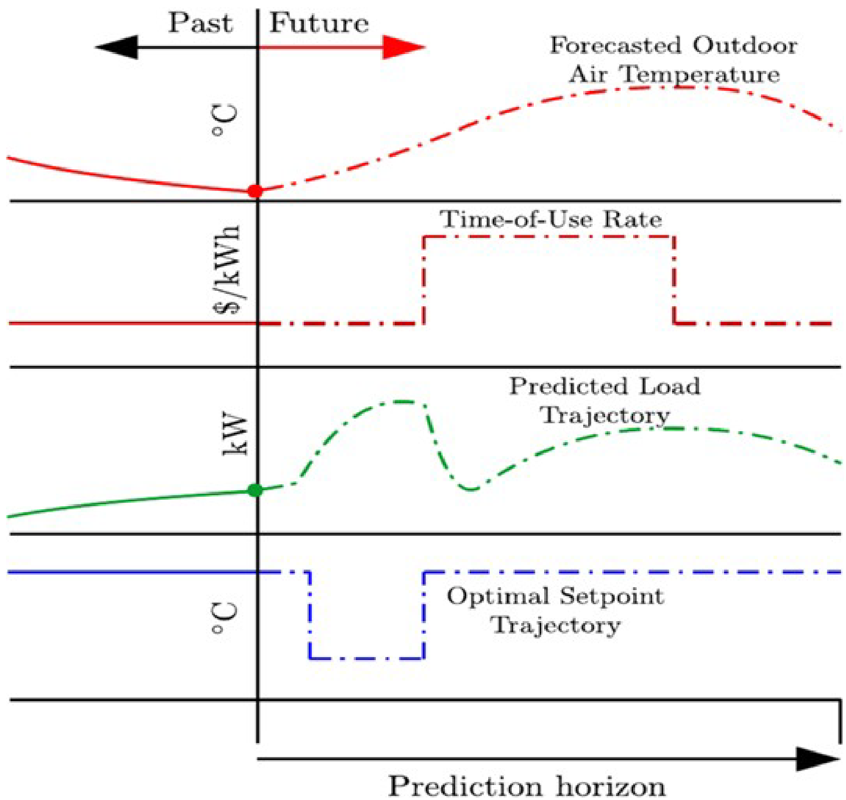


Overview of Project Design and Modeling

Demonstration of the technology will occur at two all-electric, low-income housing communities located in different California climate zones The project will test and demonstrate the AWHC with at least 25 heat pump water heaters split between the two demonstration sites. The project will also test and demonstrate the ASCC with at least two space conditioning heat pumps, where the two housing units will be selected from the group participating in the AWHC demonstration.

The project vision is to develop AHWC and ASCC that are based on a model predictive control strategy and compare their performance to basic and advanced rule-based controls. Model predictive controls (MPC) are a state-of-the-art control optimization system. In contrast to rule-based controls, MPCs have a dynamic model that represents the specific system they control and can be adapted over time based on site-specific data.

The MPC system uses the dynamic model to predict how the system will need to operate over a given time horizon in response to exogenous inputs, such as a local weather forecast. The MPC then calculates the optimal process control outputs based on the specified optimization objective (e.g., minimize cost, GHG emissions), which includes constraints for occupant preferences and equipment limitations.



Modelling Predictive Control Optimization

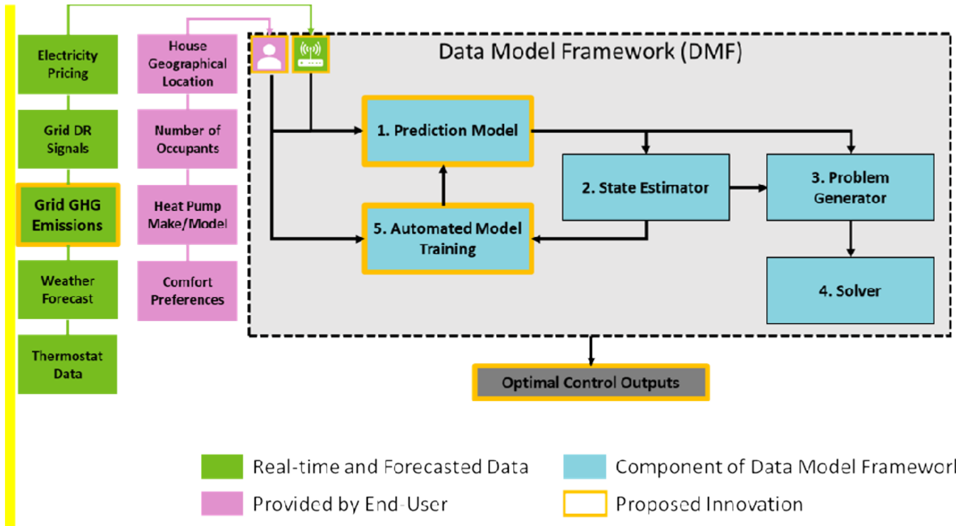
This project will develop an open-source turn-key MPC system that will be easy to use and will eliminate the need for installers or end-users to have subject matter expertise in MPC or heat pump systems. The proposed data model framework (DMF) in Figure 3 will replace the MPC subject matter expert and simplify the configuration, setup, and maintenance process.

As part of the CEC EPIC project, there are six technical tasks specific to this project:

1. Market Characterization
2. Develop Advanced Water Heating Controls
3. Develop Advanced Space Conditioning Controls
4. Test and Demonstrate Advanced Water Heating Controls
5. Further Research in Advanced Space Conditioning Controls
6. Market Barriers and Commercialization Assessment.

The project will evaluate load flexibility technologies' ability to successfully shift, shed, shape, and shimmy demand of advanced, high efficiency heat pumps for space conditioning or water heating in response to grid needs, building owner/occupant preferences, utility pricing, and DER availability". The project will demonstrate the ability to automate and optimize the shifting of space conditioning or water heating heat pump load out of the evening ramp-particularly in the Spring and Fall when the ramps are steepest—or away from times when the generation mix is producing the highest level of GHG emissions.

The project will "Demonstrate heat pump operational flexibility, combined with other technologies and strategies (e.g. demand response, DERs such as advanced on-site storage, etc.), to provide grid support under current and future generation.



Project Data Model Framework

The project was funded under the EM&T Market Assessments and Technology Assessments investment categories, as there are elements of both research goals in this study. The Market Assessments category is designed to create a better understanding of the emerging innovation and developments of new consumer markets for DR-enabling technologies and an awareness of consumer trends for smart devices. The Technology Assessments category assesses and reviews the performance of DR- enabling technologies through lab and field tests and demonstrations designed to verify or enable DR technical capabilities.

Collaboration

The EM&T program is co-funding the overall project that is led by the UC Davis's Western Cooling Efficiency Center (WCEC). The project is being designed and operated by UC Davis under a contract with the CEC's EPIC program with other grant partners. While the EM&T program is co-funding the project through a contract with WCEC, SCE is also leveraging its access to CEC EPIC projects with learnings and best practices from EPIC research activities As a founding member of WCEC, SCE has insights to ongoing research and leveraging that research to assist in this study.

Results/Status

The market characterization study has been completed. It reviewed available literature and interviewed 14 subject matter experts. This study found:

1. Based on the residential appliance saturation survey,
    a. Space conditioning heat pumps comprise 4% of CA market, up from 2% in 2009.
    b. Heat pump water heaters comprise 0.6% of CA market, up from 0.3% in 2009.
2. Many heat pumps have basic load flexibility capabilities (receive only) but are underutilized.
3. Penetration of advanced load flexibility (two-way communication) is very low.

Development of the AWHC is in continuation. The cloud environment has been built, with lab testing over a range of air and water temperatures expected in Q3 / Q4 2023. The validation testing of laboratory HPWH set-up is complete. The project team has investigated different approaches to using electricity costs and GHG emissions in the optimization. Simulation testing on AWHC approach is ongoing and initial results have shown that the MPC can shift HPWH operation to times when the electricity generation is cleaner, while still minimizing operating costs and maintaining occupant comfort[1].

The ASCC laboratory benchtop test setup has been completed. The setup is made up of the Ecobee smart thermostat, Ecobee remote temperature sensor, a small temperature control box, and building and equipment models simulated in EnergyPlus. In the remaining months of 2023, representative models for the field site buildings and equipment will be developed for EnergyPlus and integrated into the test setup.

M&V data collection is on-going at the twenty-six households who have been recruited for project field demonstrations. Baseline surveys for water heating and space conditioning have been completed and more will be administered once the AWHC and ASCC have been deployed.

The project received CEC approval to continue work after the critical project meeting in July 2022. It has received a no-cost extension from CEC and the new project end date will be Q2 2025.

[1] Loren dela Rosa, Caton Mande, Henry Richardson, Matthew J. Ellis. Integrating Greenhouse Gas Emissions into Model Predictive Control of Heat Pump Water Heaters. ACC 2023.

Next Steps

The project will continue hot water use forecast model development with data from the field demonstrations. Testing the AWHC on HPWH will begin in Q3 2023. The study will continue to focus on the following tasks:

- Testing MPC performance in simulation and on HPWH in lab.
- Expand the Data Model Framework for space conditioning system and building models.
- Develop representative EnergyPlus models for the field site buildings and equipment.
- Prepare retrofit of AWHC and ASCC and monitor control performance for 9-12 months.